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14. ABSTRACT
Progress to-date is described on the project "Effects of Subzero Temperatures and Seawater Immersion on Damage Initiation and Growth in Sandwich Composites." Funding for this two-year effort was received at Syracuse University (SU) in late February of 2007. The work since that time has focused on obtaining materials and supplies, creating the infrastructure to do the work, and on performing preparatory and exploratory experiments and analyses. To this end, freezers have been purchased for storage of sandwich laminates at 0°, -20° and -40°C, test fixtures have been designed and are being fabricated at the SU machine shop, manufacturing supplies have been procured, and a vacuum-assisted resin transfer molding (VARTM) process for fabricating sandwich panel laminates has been successfully implemented. Work in-progress includes seawater immersion and freezing studies on core and sandwich panel specimens, as well as a preliminary evaluation of the proposed crack tip element based approach for predicting energy release rates for sandwich debonding and crack kinking out of the core-to-face sheet interface. Along with a

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Effects of Subzero Temperatures and Seawater Immersion on Damage Initiation and Growth in Sandwich Composites

Interim Report for the period January 1 – June 12, 2007

Barry D. Davidson

June 12, 2007

Executive Summary

Progress to-date is described on the project "Effects of Subzero Temperatures and Seawater Immersion on Damage Initiation and Growth in Sandwich Composites." Funding for this two-year effort was received at Syracuse University (SU) in late February of 2007. The work since that time has focused on obtaining materials and supplies, creating the infrastructure to do the work, and on performing preparatory and exploratory experiments and analyses. To this end, freezers have been purchased for storage of sandwich laminates at 0°, –20° and –40°C, test fixtures have been designed and are being fabricated at the SU machine shop, manufacturing supplies have been procured, and a vacuum-assisted resin transfer molding (VARTM) process for fabricating sandwich panel laminates has been successfully implemented. Work in-progress includes seawater immersion and freezing studies on core and sandwich panel specimens, as well as a preliminary evaluation of the proposed crack tip element based approach for predicting energy release rates for sandwich debonding and crack kinking out of the core-to-face sheet interface. Along with a description of these efforts, a Gantt chart is presented that shows the project schedule through completion.

Work Completed

- Purchased freezers for storage of sandwich laminates at 0°, –20° and –40°C.
- Purchased glass fabric, graphite fabric, derakane resin, DIAB H100 PVC core, and other supplies for manufacturing sandwich laminates.
- Implemented vacuum-assisted resin transfer molding (VARTM) process for manufacturing sandwich panel laminates.
- Designed a fixture that can be used for static or fatigue 3 or 4 point bending tests. This fixture has large loading heads to prevent local crushing of the core, variable inner and outer span lengths, and is sufficiently stiff to be used for all specimens in this study. This fixture will be used in the fatigue study of undamaged and impact damaged sandwich panel laminates. Fabrication of this fixture is nearing completion (in the SU machine shop).
- Designed a "drop fixture" to create impact damage in sandwich panel laminates. The fixture will accommodate panels up to 75mm (3") wide. A 25mm (1") diameter, cylindrically shaped impact head contacts the laminate. A "capture device" captures the impactor upon its first rebound, such that only a single impact occurs on any given drop. Panel boundary conditions can be fully supported along the entire base, or simply supported at each end. The point of impact can be chosen by the user, such that the center of the impact damage will be in the correct location for subsequent testing. Two different impactors have been designed:

one has a mass of 5.1kg and one has a mass of 2.55kg. Drop heights up to 800mm can be accommodated. This means that impact energies up to 40J can be created. Further, impacts up to 20J can be created with the larger (5.1kg) mass and a small drop height, or with the smaller (2.55kg) mass and a larger drop height. Along with the user-specified variability in boundary conditions, this will ensure that an impact scenario can be developed that produces the desired amount of damage.

Work In-Progress

Immersion Studies of Core and Sandwich Laminate Specimens

Small samples of H100 core and sandwich panels with glass/epoxy face sheets are being used to perform immersion studies. Weight gain versus time data for specimens immersed in seawater and stored at room temperature and at 0°C are first being obtained for these samples. This study will continue until complete saturation is achieved, and is expected to take approximately three months. At that time, microscopy studies of these specimens [1] will be performed to ascertain the nature of the damage, the depth of water ingress, and to ascertain any significant differences between the core and sandwich specimens at the same temperature, or between two specimens of the same type at different temperatures. These specimens will then be used as part of the "Freezing Studies" described below.

Freezing Studies of Core and Sandwich Laminate Specimens

One aspect of this research program is to study moisture-saturated laminates at –20°C and –40°C. Since seawater freezes at approximately –2°C, it is clear that the moisture saturation will need to take place above this temperature. In view of the other aspects of this study, the two obvious choices are to first perform seawater saturation at either room temperature (RT) or 0°C and, once complete, bring the specimen to the desired temperature prior to testing. However, it is unclear whether the saturation temperature and/or the amount of time that the saturated specimen is held at the subzero temperature will affect the variables that are being examined, which include the debonding behavior, the debonding toughness, the damage due to impact, and the static and fatigue damaged and undamaged bending strength and failure behavior. To assist in making the decision on the method of environmental conditioning, a sub-study will be conducted using the core and sandwich laminate specimens used for the "Immersion Studies" described above. Specimens saturated at RT and 0°C will be brought to –40°C for various periods of time, and microscopy will be used to evaluate whether there are significant differences due to the saturation temperature and/or the amount of time that the saturated specimen is held at the subzero temperature. These results will be used as guidance in the choice of the environmental conditioning method. An example would be if one saturation temperature is found to be somewhat more damaging than the other, then the more damaging method would be used. However, if this damage was so severe as to dramatically degrade the interface, then it would be preferable to use the less damaging saturation temperature. Similarly, the results of this sub-study will provide important information on whether or not it is important to closely control the post-saturation time for which the specimen is held at subzero temperature. Thus, it is expected that the results of this sub-study will be the definition of the environmental conditioning protocol for all moisture-saturated specimens that are to be tested at –20°C and –40°C.

Preliminary Evaluation of CTE Approach for Predicting Interface Debonding and Crack Kinking (Analysis of Debonding Data in the Literature)

Two of the goals of this research are to (1) provide a relatively simple analysis to obtain the energy release rate for interfacial debonding and (2) develop a method that is capable or predicting the path of crack advance, i.e., whether the crack remains in the vicinity of the interface versus whether it kinks and progresses into (or through) the core. The crack tip element (CTE) analysis was proposed as the approach through which both of these goals could be fulfilled, and the debonding experiments to be performed as part of this research will help in the development and refinement of this approach. However, prior to conducting these experiments, it was deemed useful to first examine existing data in the literature using the CTE approach. To this end, the data in references [2-5] are being re-analyzed. When a singular field-based definition of mode mix is adopted, the results to-date indicate that the CTE approach can be used to produce essentially the same values of energy release rate and mode mixity as the finite element method for the materials, geometries and loadings considered in these works. This same correspondence has been obtained in many previous studies of the CTE approach, and validates that the basic mechanics of the CTE are correct. The key issue, however, is whether a "CTE/non-singular field" (CTE/NSF) approach can be used as part of a methodology to predict when the debond kinks out of the interface. A variety of potential approaches (as described in the original proposal) are being considered for this and are being applied to the existing data sets from these references. The most promising approach(es) will then be used to evaluate whether the proposed test program is sufficient, i.e., whether it can be used to fully evaluate the accuracy of any proposed method. It is possible that this may result in a few small additions to the debonding test program, which will begin once this analysis of debonding data in the literature is complete.

Plans, Staffing and Timeline

Figure 1 presents a Gantt chart that shows the schedule-of-work through project completion. This schedule of work agrees with the budgetary spending plan outlined in the original proposal. That is, the period from grant inception through August 2007 may be thought of as being used for "preparatory work" that will enable the test programs to quickly ramp-up starting in September 2007. Staffing for this project is also proceeding as expected. Outside of the PI, a graduate student working hourly and a post-doctoral researcher have been the primary contributors to this effort. The post-doctoral researcher will continue to devote part-time effort to this project, and a new graduate student will join in this research full-time on July 30, 2007 and will continue working on this project through its end-date.

Conclusions

Work in this first period since project inception has primarily been preparatory in nature. Materials and supplies have been procured, test fixturing has been designed and is being fabricated, long lead-time preliminary seawater saturation studies are in-progress, and the details of the analyses that will be used are being worked-out using data that is available in the scientific literature. These efforts are progressing according to the time and budgetary schedules that were originally planned, and are laying the groundwork to successfully perform the intensive testing and analysis efforts that are to come.

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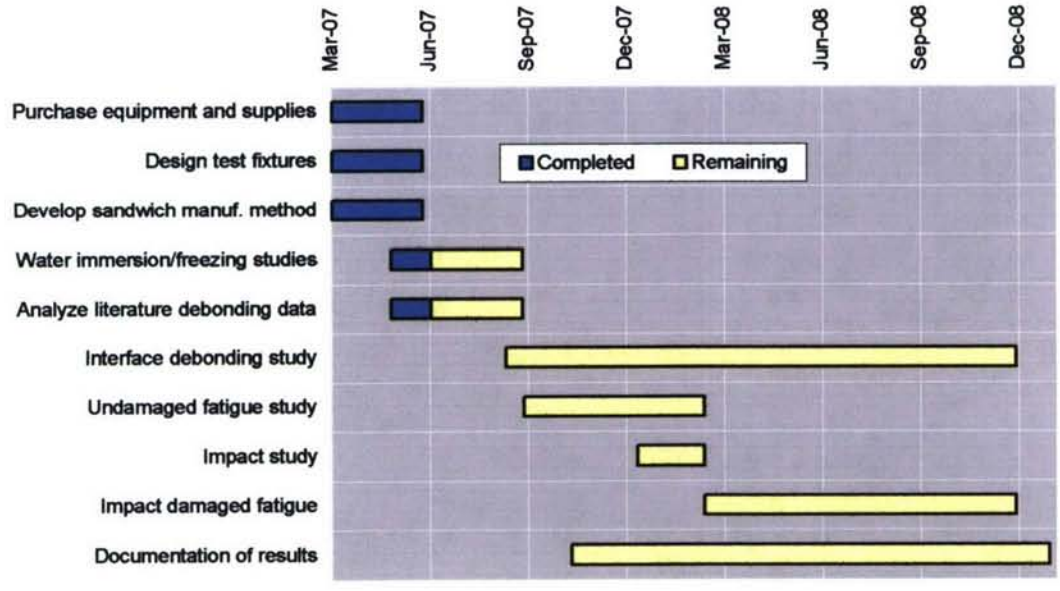

Figure 1. Schedule-of-work through project completion.